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Title: **242 Pu CRITICAL MASS**

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^{242}Pu CRITICAL MASS

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Abstract

Large amounts of ^{242}Pu (0.3 to 0.8 mg/g UO_2) are present in spent nuclear reactor fuel with more being produced on a daily basis. For stabilization and reprocessing of spent fuel, criticality safety data are needed to ensure that ^{242}Pu is handled safely. The calculated bare critical mass of ^{242}Pu is 85.80±3.46 kg at a density of 19.86 g/cm^3. This critical mass was derived based upon calculations of critical experiments that used up to 24 kg ^{242}Pu. The previous critical mass derivation should be reasonably accurate until such time that integral data can be obtained.

Introduction

In 1979 a set of experiments was performed at Los Alamos Scientific Laboratory using circular plates of plutonium with high ^{242}Pu content[1]. The purpose of these experiments was to verify ^{242}Pu data by testing the ability to predict criticality for systems composed largely of ^{242}Pu and to derive the critical mass of ^{242}Pu. Because large quantities of ^{242}Pu were not available, the systems were driven to near critical with ^{239}Pu or highly enriched uranium (HEU). Therefore, the configurations also included plates of HEU or ^{239}Pu. Some stacks of plates were unreflected. Others were reflected by steel (Fe), beryllium (Be), or depleted uranium (DU). The experiments were slightly subcritical with extrapolations to critical configurations and are described in detail in Reference 1. Calculational results of the different experimental configurations are shown in Table 1.

Table 1. Calculational Results of the ^{242}Pu Critical Experiments

Code (Cross-Section Set) ⇒ Experiment ⇓	MCNP (CE ENDF/B-V)`	MCNP (CE ENDF/B-VI)
Bare ^{239}Pu	1.0044±0.0015	1.0049±0.0015
Be Reflected ^{239}Pu and ^{242}Pu	0.9950±0.0016	0.9926±0.0017
DU Reflected ^{239}Pu and ^{242}Pu	1.0103±0.0016	1.0069±0.0019
Fe Reflected ^{239}Pu and ^{242}Pu	0.9943±0.0016	0.9931±0.0016
End-Driven Bare ^{239}Pu and ^{242}Pu	1.0008±0.0017	0.9990±0.0015
Center-Driven Bare ^{239}Pu and ^{242}Pu	1.0080±0.0017	1.0085±0.0017
Fe/DU Reflected HEU and ^{242}Pu	1.0004±0.0016	0.9941±0.0014

Code (Cross-Section Set) ⇒ Experiment ⇓	TWODANT (30 group ENDF/B-V)	TWODANT (30 group ENDF/B-VI)
Bare ^{239}Pu	1.0029	1.0037
Be Reflected ^{239}Pu and ^{242}Pu	0.9925	0.9906
DU Reflected ^{239}Pu and ^{242}Pu	1.0060	1.0039
Fe Reflected ^{239}Pu and ^{242}Pu	1.0021	0.9993
End-Driven Bare ^{239}Pu and ^{242}Pu	0.9979	0.9971
Center-Driven Bare ^{239}Pu and ^{242}Pu	1.0027	1.0027
Fe/DU Reflected HEU and ^{242}Pu	1.0116	1.0014

Code (Cross-Section Set) ⇒ Experiment ⇓	TWODANT (44 group ENDF/B-V)	TWODANT (28 group ABBN-93)
Bare ^{239}Pu	1.0050	1.0038
Be Reflected ^{239}Pu and ^{242}Pu	0.9993	0.9929
DU Reflected ^{239}Pu and ^{242}Pu	1.0015	1.0030
Fe Reflected ^{239}Pu and ^{242}Pu	0.9900	0.9791
End-Driven Bare ^{239}Pu and ^{242}Pu	1.0025	0.9971
Center-Driven Bare ^{239}Pu and ^{242}Pu	1.0064	1.0082
Fe/DU Reflected HEU and ^{242}Pu	1.0041	0.9915

It was estimated in 1979 that a bare sphere of pure ^{242}Pu has a critical mass of about 80-kg at a density of 19.86 g/cm^3. It was also estimated that a bare square cylinder (height = diameter) of pure ^{242}Pu has a critical mass of about 90 kg at a density of 19.86 g/cm^3. The two pure ^{242}Pu models were found using calculational methods (KENO and ANISN with 16 group cross sections) which were biased using calculations of the experimental configurations.

Calculations

Based on the calculational results for the seven experimental configurations, four cross section libraries consistently yielded calculational results within the experimental uncertainties, Mendf5, Mendf6, ABBN-93 and 44-group ENDF/B-V. These four libraries were used to determine the bare spherical critical mass of a ^{242}Pu metal system at a density of 19.86 g/cm^3, bare, reflected by iron (7.87 g/cm^3 and 100 wt% Fe), and reflected by water. The results are shown in Table 2.

Table 2. Critical Mass Values of ^{242}Pu

Code (Cross Section Library)	ONEDANT (ABBN-93)	ONEDANT (44-Group ENDF/B-V)	ONEDANT (Mendf5)	ONEDANT (Mendf6)
Reflector	Calculated Critical Mass ^{242}Pu Metal (kg ^{242}Pu)			
Bare	88.83	80.00	86.40	87.97
Iron	55.41	45.36	48.10	48.80
Water	82.34	82.48	78.30	79.24
	Calculated Critical Mass $^{242}PuO_2$ (kg ^{242}Pu)			
Bare	418.44	384.76	363.44	366.66
Iron	286.82	244.67	224.94	225.60
Water	395.88	359.28	342.15	366.94

The critical masses were calculated based on a simple average of the calculations shown in Table 2. The calculated bare metallic critical mass is 85.80 kg ^{242}Pu. The calculated iron reflected metallic critical mass is 49.42 kg ^{242}Pu. The calculated water reflected metallic critical mass is 80.59 kg ^{242}Pu. The calculated bare oxide critical mass is 383.32 kg ^{242}Pu. The calculated iron reflected metallic critical mass is 245.51 kg ^{242}Pu. The calculated water reflected metallic critical mass is 366.06 kg ^{242}Pu.

The different experimental assemblies had uncertainties ranging from ±0.0054 to ±0.0121 in the values of the calculated k_{eff}. Calculation of the experimental assemblies ranged from 0.9791 to 1.0116.

The uncertainty in mass, based upon calculation of each experimental configuration for the four cross section libraries, is ±3.94 kg ^{242}Pu. This analysis assumes that the uncertainty is due entirely to the ^{242}Pu cross section data. This is obviously a false assumption, but it does increase the ^{242}Pu critical mass uncertainty.

The uncertainty of the calculated critical masses was derived using standard deviation methodology. The uncertainty in the bare metallic critical mass is ±3.46 kg ^{242}Pu. The uncertainty in the iron reflected metallic critical mass is ±3.69 kg ^{242}Pu. The uncertainty in the water reflected metallic critical mass is ±1.85 kg ^{242}Pu. The uncertainty in the bare oxide critical mass is ±21.84 kg ^{242}Pu. The uncertainty in the iron reflected oxide critical mass is ±25.13 kg ^{242}Pu. The uncertainty in the water reflected oxide critical mass is ±19.41 kg ^{242}Pu.

Conclusion

The previous uncertainties were combined to yield the total uncertainty in the various ^{242}Pu calculated critical masses. The calculated critical masses with the associated uncertainties are shown in Table 4. The uncertainty associated with calculation of the experimental configurations was not applied to the $^{242}PuO_2$ calculated critical masses. These critical mass derivations should be reasonably accurate until such time that integral data can be obtained.

Table 4. Final Critical Mass Values and Their Uncertainties

Reflector	Critical Mass ^{242}Pu Metal (kg ^{242}Pu)	Δk_{eff} associated with mass uncertainty
	^{242}Pu Metal	
Bare	85.80±3.46	±0.0089
Iron	49.42±3.69	±0.0165
Water	80.59±1.85	±0.0050
	$^{242}PuO_2$	
Bare	383.32±21.84	±0.0091
Iron	245.51±25.13	±0.0031
Water	366.06±19.41	±0.0084

Calculational results of the critical mass values given in Table 4 using MCNP and ONEDANT with various cross section sets are shown in Table 5. Many of the calculational results fall outside the derived uncertainty.

Table 5. Calculational Results of the Estimated ^{242}Pu Critical Mass

^{242}Pu Metal			
Code (Cross-Section Set)	Bare	Iron	Water
MCNP (Continuous-energy ENDF/B-V)	0.9970±0.0018	0.9851±0.0018	1.0046± 0.0017
MCNP (Continuous-energy ENDF/B-VI)	0.9966±0.0020	0.9769±0.0019	0.9998± 0.0017
MCNP (Continuous-energy JENDL 3.2)	1.0532±0.0022	1.0291±0.0020	1.0605± 0.0019
TWODANT (44-group ENDF/B-V)	1.0160	1.0196	1.0225
TWODANT (Mendf5)	0.9985	1.0060	1.0063
TWODANT (Mendf6)	0.9972	1.0028	1.0038
TWODANT (ABBN-93)	0.9927	0.9761	0.9955
$^{242}PuO_2$			
MCNP (Continuous-energy ENDF/B-V)	0.9816±0.0020	0.9741±0.0021	0.9883±0.0019
MCNP (Continuous-energy ENDF/B-VI)	0.9884±0.0019	0.9771±0.0018	0.9895±0.0017
MCNP (Continuous-energy JENDL 3.2)	1.0398±0.0020	1.0273±0.0019	1.0407±0.0020
TWODANT (44-group ENDF/B-V)	0.9983	0.9923	1.0008
TWODANT (Mendf5)	1.0076	1.0055	1.0102
TWODANT (Mendf6)	1.0066	1.0053	1.0089
TWODANT (ABBN-93)	0.9842	0.9733	0.9856

References

1. R. W. Brewer, "Critical Experiments Performed Using Plates of Plutonium-242, HEU and Plutonium-239," International Handbook of Evaluated Criticality Safety Experiments, SPEC-MET-FAST-004, Nuclear Energy Agency, Organization for Economic Co-Operation and Development.